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MIDDLE DEVONIAN SKAŁY FORMATION IN THE HOLY CROSS MOUNTAINS (POLAND) – FORMAL DESCRIPTION AND SUBDIVISION BASED ON NEW FIELD DATA

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Abstract: The well-known fossiliferous and lithologically variable clay-carbonate series in the Łysogóry Region (northern part of the Holy Cross Mts, central Poland), enclosed between the Middle Devonian *Amphipora* dolomites and limestones (Kowala Formation) and siliciclastics (Świętomarz Beds), is defined formally as the Shaly-Calcareous Skały Formation. This Upper Eifelian to Middle Givetian, ca. 250–280 m thick unit, consists of marly and clay shales, interbedded many times with various limestone types (including encrinite and biohermal varieties), as well as with marls and siltstones. Its diagnostic feature is the presence of variable skeletal accumulations, formed by exceptionally numerous, well-preserved and diverse macrofauna (including brachiopods, corals, crinoids, bryozoans), described since the 19th century. The stratotype is located in the eastern slope of the Dobruchna stream near the Skały village and belongs to the Silurian to Upper Devonian Grzegorzowice-Skały section. Compared to the previously used term, Skały Beds *sensu* Pajchlowa (1957), the lower boundary is redefined, owing to a new exposure in the active Skała Quarry, and placed higher, at the base of the famous brachiopod shales (set XIV of Pajchlowa), instead of the formerly accepted lower boundary at the base of set XIII. Set XIV is formally distinguished as the Dobruchna Brachiopod Shale Member. The higher part of the Skały Fm (sets XV–XXVA) is not subdivided further, as the poorly exposed succession, including in particular the type area, precludes a more accurate recognition of lithological variability. The upper boundary of the Skały Fm is placed at the top of set XXV *sensu* Pajchlowa (1957), corresponding to the boundary between subsets XXVA and XXVB *sensu* Malec and Turnau (1997). A hypostratotype of the upper boundary is selected in the outcrop M0 at Miłoszów, 2.5 km westwards from the type section, allowing recognition of the diachroneity of lithological change defining the transition from the Skały Fm to Świętomarz Beds. A borehole situated in a key location would be an obvious next step in the further elucidation of the stratigraphic sequence of the Łysogóry Region.

Key words: Lithostratigraphy, Skały Formation, Dobruchna Member, Middle Devonian, Łysogóry Region, Holy Cross Mts.

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INTRODUCTION

The thick series of Middle Devonian shales and limestones, cropping out near Nowa Słupia in the northern Holy Cross Mts (HCMts, Łysogóry Region; Fig. 1), has been known since its first detailed descriptions by Zeuschner (1869) as a unique stratigraphic unit in the Holy Cross Mts (HCMts), distinguished by the abundance and variety of fossils as well as changing lithology (Pajchlowa, 1957; Kłossowski, 1985; Malec and Turnau, 1997; Halamski and Zapalski, 2006; Woroncowa-Marcinowska, 2012). These fragmentarily exposed strata, most commonly referred to as

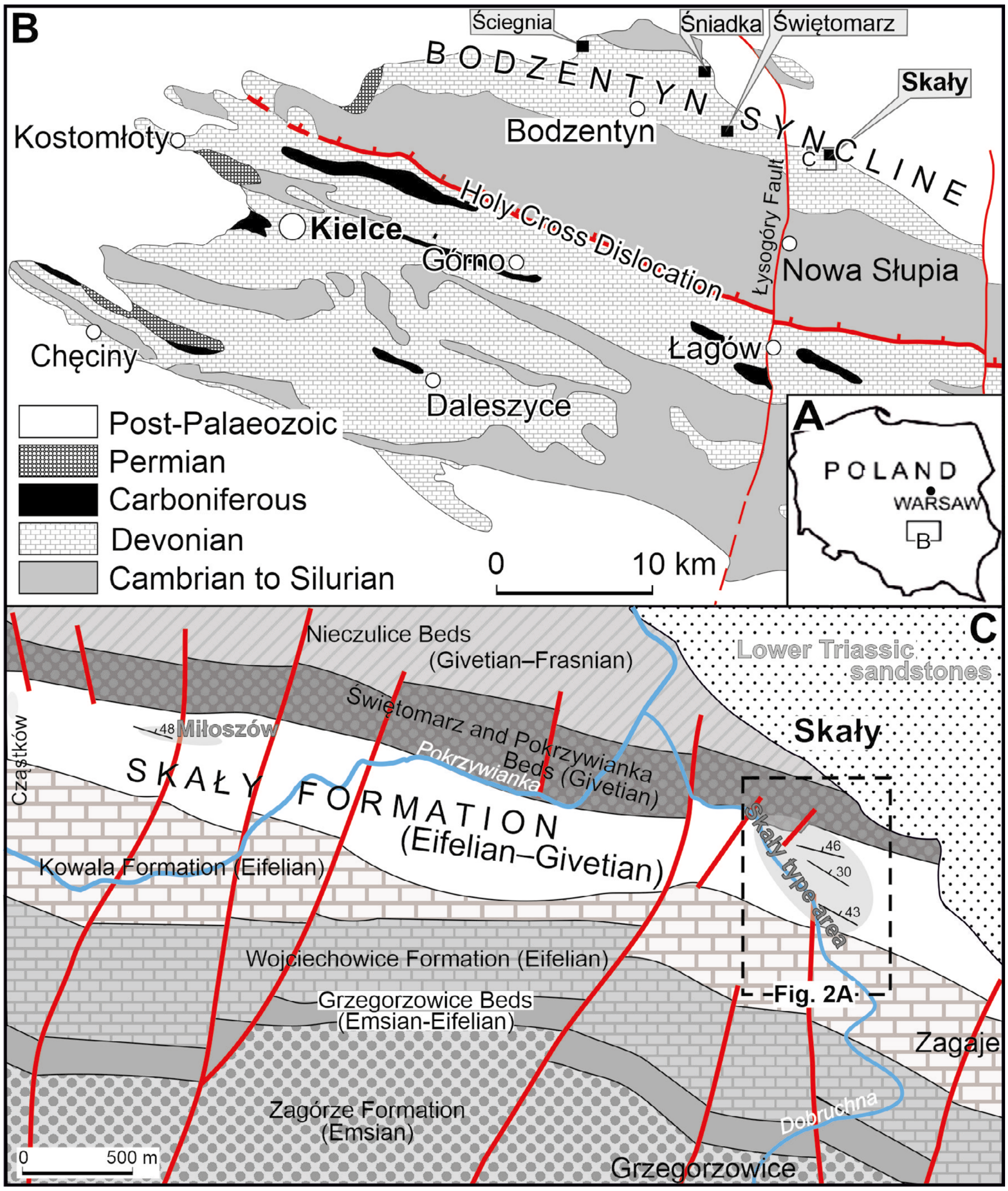

Fig. 1. Location of outcrops of the Skały Formation (see Fig. 2A for details). **A.** Location of the study area (rectangle) in Poland. **B**. Geological sketch map of the Holy Cross Mountains (after Halamski *et al*., 2022, fig. 1B), with the Skały Formation studied at the Grzegorzowice-Skały and Świętomarz-Śniadka areas (indicated). **C**. Geological map of the Grzegorzowice-Skały type area (based on Filonowicz, 1968, fig. 3), with the Skały type area and Miłoszów outcrops. Faults are marked with red lines.

an informal unit, called the Skały Beds (in Polish: warstwy skalskie) or, less correctly, as the “Skały Formation” (in Polish: formacja skalska), are known worldwide for their value in cognitive studies of the Devonian system. This succession has been the subject of an exceptionally large number of publications, especially on its palaeozoological aspects (see reviews in Pajchlowa, 1957; Adamczak, 1976; Halamski, 2004).

The Middle Devonian succession of the reference Grzegorzowice-Skały section in the Dobruchna stream valley (Figs 1C, 2A) was relatively well recognized, owing to excavation work at the turn of 1940s and 1950s, carried out by a team of geologists and palaeontologists from the Museum of the Earth in Warsaw (Muzeum Ziemi PAN) and the Polish Geological Institute (Państwowy Instytut Geologiczny), coordinated by Maria Pajchlowa (Fig. 3D; summarized in Pajchlowa, 1957). However, despite its importance, this succession still has not been defined or divided, according to the codified principles of stratigraphy (Racki and Narkiewicz, 2006; Murphy *et al*., 2022). Until now, informal stratigraphic terms are used to describe the succession, including the confusing name “Skały Formation”, introduced for the first time by Adamczak (1976) and maintained by Kłossowski (1985). The unit, however, remained an informal one, as the authors did not designate its stratotype, failed to provide a lithological diagnosis, and provided no definition of its boundaries (see Racki and Narkiewicz, 2006). In spite of this, the inventory of Polish lithostratigraphic units (Marcinowski, 2004) refers to the “Skały Formation (fm)” as a formal lithostratigraphic

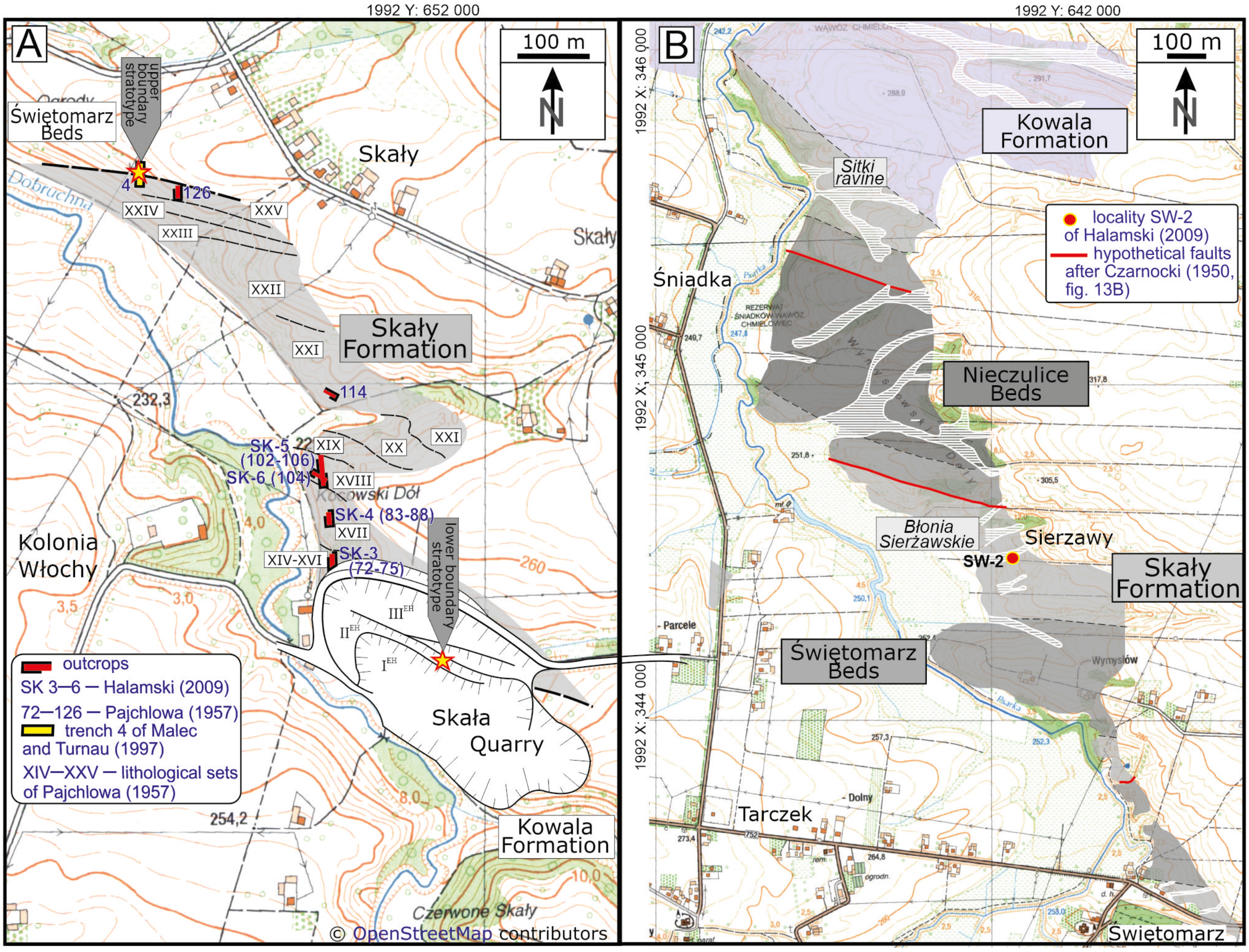

Fig. 2. Location of the outcrops in the Grzegorzowice-Skały and Świętomarz-Śniadka areas. **A**. Location of the boundary stratotypes of the Skały Formation in the type area on the topographic map of Poland (*Mapa Topograficzna Polski 1:10000*, *sheet M-34-43-A-d-1*, 2001; boundaries of the Skała Quarry, as of 2021), with geological sketch according to Pajchlowa (1957). I^{EH}, II^{EH}, III^{EH} – excavation levels; XIV–XXV – lithological sets (Pajchlowa, 1957; for more details, see Fig. 5). The outcrops available today are mostly abandoned excavations of Pajchlowa and Malec. **B**. Topographic map of Poland, showing the Świętomarz-Śniadka section with location of the Skały Fm. exposures; geological sketch according to Czarnocki (1950, fig. 13A), modified by the introduction of the Nieczulice Beds (instead of the Skały Fm) in the area east of Śniadka (after Filonowicz, 1968, tab. 7, and Kłossowski, 1981, fig. 1). The complicated tectonic structure of the Świętomarz fault zone (see Mizerski, 1981) and poor outcrops imply a much more speculative cartographic interpretation, as suggested by the probable occurrences of Nieczulice Beds also at least at Błonia Sierżawskie.

unit. The lack of a systematic, well-documented description remains an obstacle to further research, all the more taking into account the facies variability known from comparisons with the less known Świętomarz-Śniadka section along the Psarka (or Ponikła) River, near Bodzentyn, 10 km NW of the Grzegorzowice-Skały section (e.g., Kłossowski, 1981, 1985; Figs 1B, 2B).

The present work is a first step towards overcoming these difficulties by formulating a more exact lithostratigraphic framework, scoped on the lithological relations in the best studied area in the vicinity of Nowa Słupia. This clarification is partial, however, as it does not include the complete, formal division of the marly series, here referred to as the Shaly-Calcareous Skały Formation (in Polish: formacja łupkowo-wapienna ze Skał). The present authors are convinced that the current recognition of its lithological variability, significantly limited by the degree of exposure, allows exclusively an incomplete division of the Łysogóry region sequence. Therefore, only one distinctive subordinate unit has been proposed here as the Dobruchna Member, embracing the celebrated brachiopod shales (complex XIV of Pajchlowa, 1957), thought of as an Upper Eifelian Konzentrat-Lagerstätte by Halamski and Zapalski (2006). This article is intended to be a step towards a complete formal lithostratigraphic division of the Devonian system in the HCMts, supplementing the units, designated in Narkiewicz *et al.* (1990), Malec (2005), Narkiewicz and Narkiewicz (2010) and Wójcik (2015).

Following Becker *et al.* (2020) in "The Geologic Time Scale 2020", in the entire text Eifelian and Givetian substages/subages are spelt with capitals (Lower/Early Givetian and so on).

HISTORICAL ACCOUNT

It is often accepted that the first reports on the fossiliferous Devonian strata in the northern HCMts were published in German journals by Ludwig Zeuschner in 1866 and 1869 for the Świętomarz-Śniadka and Grzegorzowice-Skały sections, respectively (Zeuschner, 1866, 1869). Notably, Zeuschner published his results also in Polish (spelt Ludwik Zejszner, 1867, 1870), and an information from the Kingdom of Poland on the fossil-rich strata between Grzegorzowice (formerly Grzegorzewice) and Skały-Zagaje, similar to the Rhenish strata, was immediately distributed in Russia (Anonymous, 1867, 1869). Fossils from Skały quickly became widely known and were familiar, among others, to the prominent British brachiopod worker Thomas Davidson (Davidson, 1882, p. 51).

However, already Georg Gottlieb Pusch (1833, pp. 62, 64–65, 100; 1837, pl. 2) had mentioned and marked on his map dark, fine-grained and 'stinking' limestones (with corals and crinoids) and shales in a belt extending from Bodzentyn to Cząstków (= Bodzentyn Syncline in the present terminology; Czarnocki, 1950). Nevertheless, more details, especially on outcrops near Śniadka and Sierżawy (now Szerzawy), had been provided in the still earlier, overlooked work of Adolf Schneider (1829, pp. 458–462).

In the first systematic surveys initiated in the 19th century, only a few distinctive lithologic units or slices of the Skały Fm were mentioned by distinguished researchers, studying the HCMts (Fig. 3A–C). Quite paradoxically from the point of view of the present authors, the easy to interpret, monoclinal Grzegorzowice-Skały succession had less significance for the elaboration of the stratigraphic schemes of Gürich (1896) and Sobolew (1909) than the Świętomarz-Śniadka area. Zeuschner (1869) recognized fossiliferous shaly clays with two limestone layers, thought of as the 40–60 m thick "Skały Shales" (in the Polish version only, Zejszner, 1870, p. 86), comparable with the strata in the Świętomarz-Śniadka section. Also, Gürich (1896, pp. 46–55, 104–105, 494–495) reported only the "Brachiopodenmergel" with *Calceola*, overlain by the Coral Bed, but interbedded along dislocations with fissile clayey shales with *Cardiola retrostriata* (Fig. 3E), assigned to the Upper Devonian "*Retrostriata*-Schiefer" (see also Gürich, 1900, p. 375). The base of the *Calceola* Stage (lower Middle Devonian) would also be tectonic, owing to a direct contact with the *Amphipora* dolomite, belonging purportedly to the *Stringocephalus* Stage (upper Middle Devonian; see a similar early interpretation of Sobolew, 1903–1904; Fig. 3G). Hence, Siemiradzki (1903, fig. 2, pp. 119, 125) proposed the presence of a fold, overthrown to the south, in order to explain this enigmatically reversed succession (Fig. 3F).

Importantly, in the context of later confusion, related to the age of the discussed strata (see below), Sobolew (1909) had decisively corrected these superposition errors in the Grzegorzowice-Skały succession much earlier. He claimed that the Stringocephalus limestone at Zagaje is of Eifelian age (Calceola Stage), according to the new data of Schmidt (1905) from the Eifel Mts (Sobolew, 1909, pp. 98–99, 151–152, fig. 2). The Calceola strata above the Brachiopod Shale were attributed by him to the Crinoid Beds, followed in the section by the new units: Sierżawy Beds (clayey shales, interbedded with layered and nodular limestones) and Świętomarz Shale/Beds (greywacke sandstones and shales; Sobolew, 1909, pp. 87–99, 137). Despite critiques by Czarnocki (1950, p. 68), the lithostratigraphic successions and ages delineated by Sobolew in both Łysogóry sections correspond well overall with the recent schemes (Fig. 4). The alleged correlations with the Eifel Mts succession are now evidently questionable due to the diachronous nature of the allegedly marker units (e.g., Crinoid Beds – Struve, 1955; see below).

Quite surprisingly from the modern point of view, the first stratigraphic proposals were based mainly on the exploration of the Świętomarz-Śniadka section, with strongly folded and faulted strata, but easier to access, owing to a location near the Suchedniów-Starachowice road. The tectonic complications, paired with lateral facies changes, recognized already by Michalski [(1888; see evolving concepts from Siemiradzki, 1903, to Woroncowa-Marcinowska, 2012, in the original geological cross-sections in digital Supplementary Material (SM)], and sparse outcrops resulted in oversimplified treatments of the Skały- and Świętomarz-type deposits (in today's terms). This exposure constraint prompted a critical evaluation of the proposals of Gürich (1896, pp. 105 and 494–495) by Sobolew (1904, 1909).

The Middle Devonian age of the strata here referred to as the Skały Fm and a direct correlation with the reference Eifel succession of Germany was clear already for Zeuschner (1866, 1869; see also Anonymous, 1869). Its stage assignment evolved from the Eifelian (*Calceola* stage) only, as conceived by Trejdosiewicz (1875) and Gürich (1896), to the upper Eifelian and lower Givetian (*Stringocephalus* Beds) according to Sobolew (1909). The erroneous age assignments by Zeuschner and Gürich, excessively complicating the understanding of the simple Grzegorzowice-Skały monocline (Fig. 3E–G; SM/Fig. 2), resulted from repeated erroneous identifications of the Eifelian–Givetian terebratulide genus *Bornhardtina* as the Givetian marker species *Stringocephalus burtini*, started with the paper by Zeuschner (1869, p. 265; see Fig. 4 and reviews in Pajchlowa, 1957; Adamczak, 1976; Filonowicz, 1968 and Halamski, 2004).

The modern stage of research was initiated by Czarnocki's tectonic-cartographic work (1950), focused on the search for iron ore, paired with palaeontological field work, carried out by the workers from the Museum of Earth of the Polish Academy of Sciences between about 1946 to 1954 (Biernat, 1953, p. 300; Kiepura, 1973, p. 325). This stage was summarized by Pajchlowa (1957), who divided the formation into thirteen lithological units (sets XIII–XXV; in Polish: kompleksy XIII–XXV). The three-fold scheme of Sobolew (1909; p. 527) was refined by Kłossowski (1981, 1985), who described three 'members' of the informal "Skały Fm": Dobruchna Brachiopod Shale, Sitka Coral-Crinoid Limestone and Sierżawy (see also Woroncowa-Marcinowska, 2012; Fig. 4). Later, Malec and Turnau (1997) proposed an informal three-fold subdivision of their Skały Beds (Fig. 5), into lower, middle and upper parts, defined by reference to the complexes of Pajchlowa (1957).

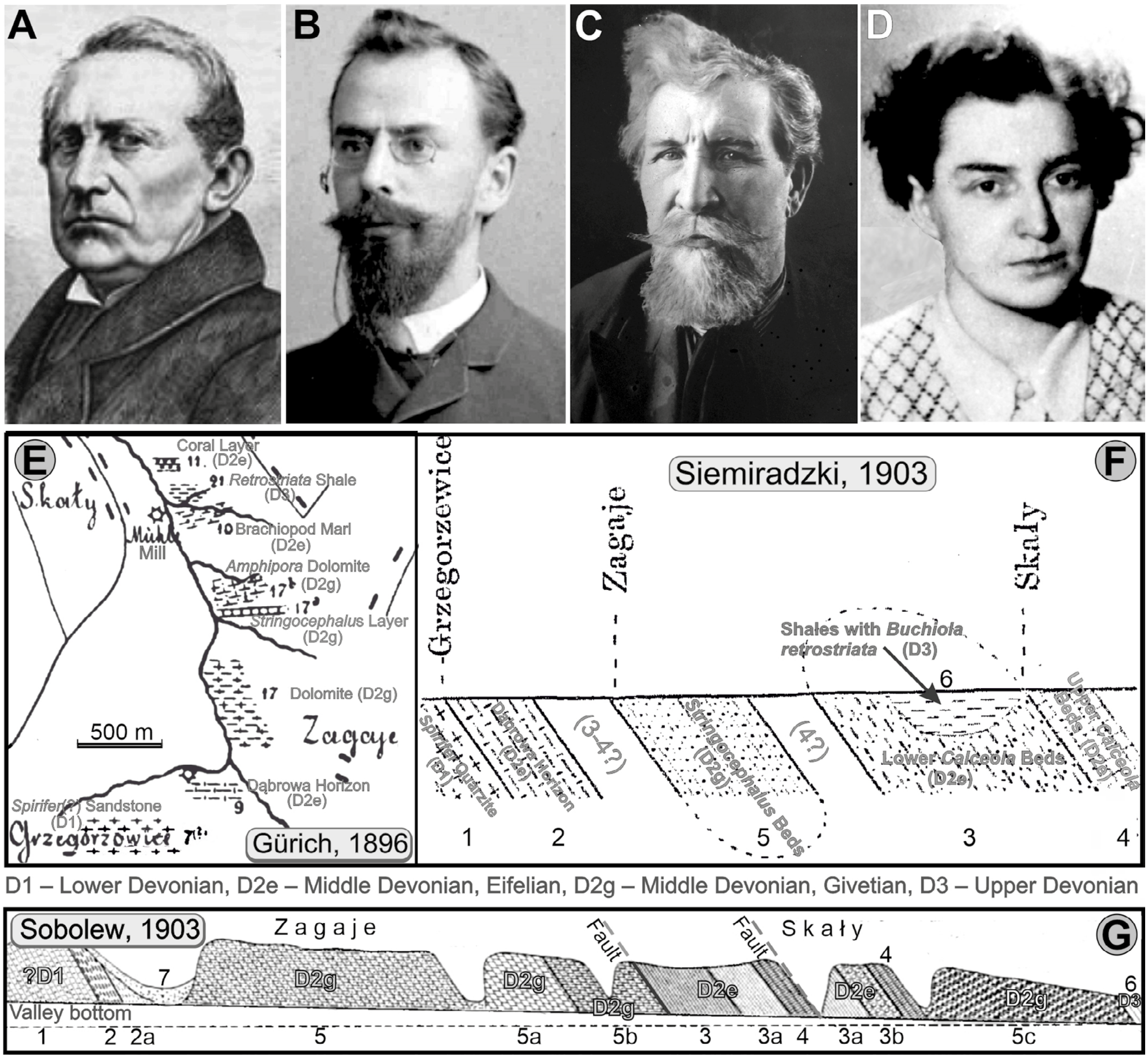

Fig. 3. Historical setting of early investigations of the Skały Formation (see also SM). **A–D**. Successive outstanding researchers of the Devonian system in the Holy Cross Mts in the late 19th and 20th centuries, who made a significant contribution to the documentation and concept of the Skały Fm. A – Ludwig Zeuschner (Ludwik Zejszner; 1805–1871, photo from Werner, 2022), discoverer of the formation in 1866; B – Georg Gürich (1859–1938; courtesy of the archives of the University of Wrocław, photo sign. AUW.S168/394), who is the first to paleontologically work out the abundant fossils; C – Dymitr Sobolew (1872–1949; photo courtesy of Jerzy Dzik), who first correctly interpreted the succession order and age of formation in 1909; D – Maria Pajchlowa (1919–1996), the initiator and leader of research project on the geology of the Grzegorzowice-Skały area, and the author of the most detailed description of the succession (from Bagińska, 2020, p. 114). **E–G**. Misunderstanding of the stratigraphic succession in the Grzegorzowice-Skały section, illustrated on the Gürich's sketch map (1896, p. 47; E), which led to an overly complicated (?nappe) tectonic interpretation by Siemiradzki (1903, p. 123; F), and double-fault interpretation by Sobolew (1903–1904; G); 1 – sandstone; 2 – marly shale, 2a – limestone, *Cultrijagatus* Beds; 3 – marly shale, 3a – clayey shale, 3b – coral marl; 4 – crinoid limestones, Crinoid Beds; 5 – dolomites, 5a – *Stringocephalus* limestones, 5b – *Amphipora* dolomites, 5c – sandstones, shales, ?dolomites; 6 – limestones with *Phillipsastrea hennahi*, 7 – valley deposits; for others see Fig. 3F; note a transitional position of Crinoids Beds between the Eifelian an Givetian stages.

On the other hand, Filonowicz (1963, 1968) noticed in the field mapping only two separate units, and the lower one contains the following subunits: brachiopod shales, marls, and *Microcyclus* beds. The unit would thus correspond likely to sets XIV–XIX *sensu* Pajchlowa (1957).

Moreover, some tectonic-stratigraphic interpretations of the Skały Fm succession, exemplified by Adamczak (1976) and Woroncowa-Marcinowska (2002) for the Grzegorzowice-Skały section, as well as by Woroncowa-Marcinowska (2012) for the Świętomarz-Śniadka section, revived the former peculiar concepts (Fig. 3E–G). It may be mentioned that the interpretation of the strata belonging to the "Skały Formation" (*sensu* Woroncowa-Marcinowska, 2002), cropping out at the southern and northern extremities of the outcrop area on the eastern slope of the Dobruchna valley as coeval (Woroncowa-Marcinowska, 2002) was refuted by Halamski (2005, p. 186) on the basis of brachiopods (a wide array of Eifelian taxa in the set XIV, *Stringocephalus* in the set XXV; see below).

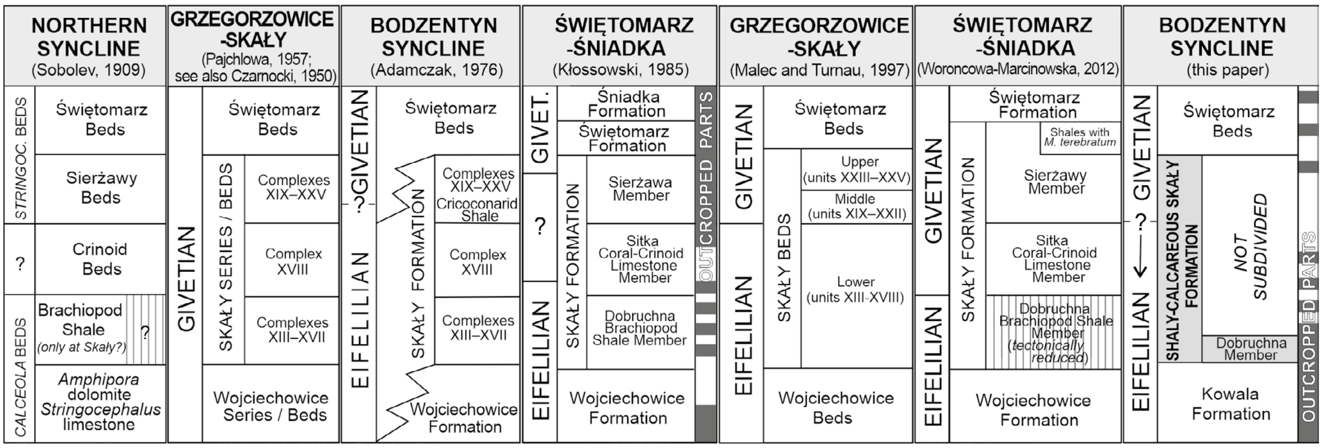

Fig. 4. Comparison of the different subdivisions of the Skały Formation, starting with the Sobolew (1909) stratigraphic scheme (for extended historical summary see Gürich, 1896, pp. 14–15, and Adamczak, 1976, fig. 5), with additional emphasis on limited outcropping of the shaly-calcareous series in both areas. Note that Sobolew (1909) understood "brachiopod shale" to be the equivalent of the entire lower part of the Skały Fm, and Dobruchna Mbr *sensu* Kłossowski (1981, 1985) had the same meaning.

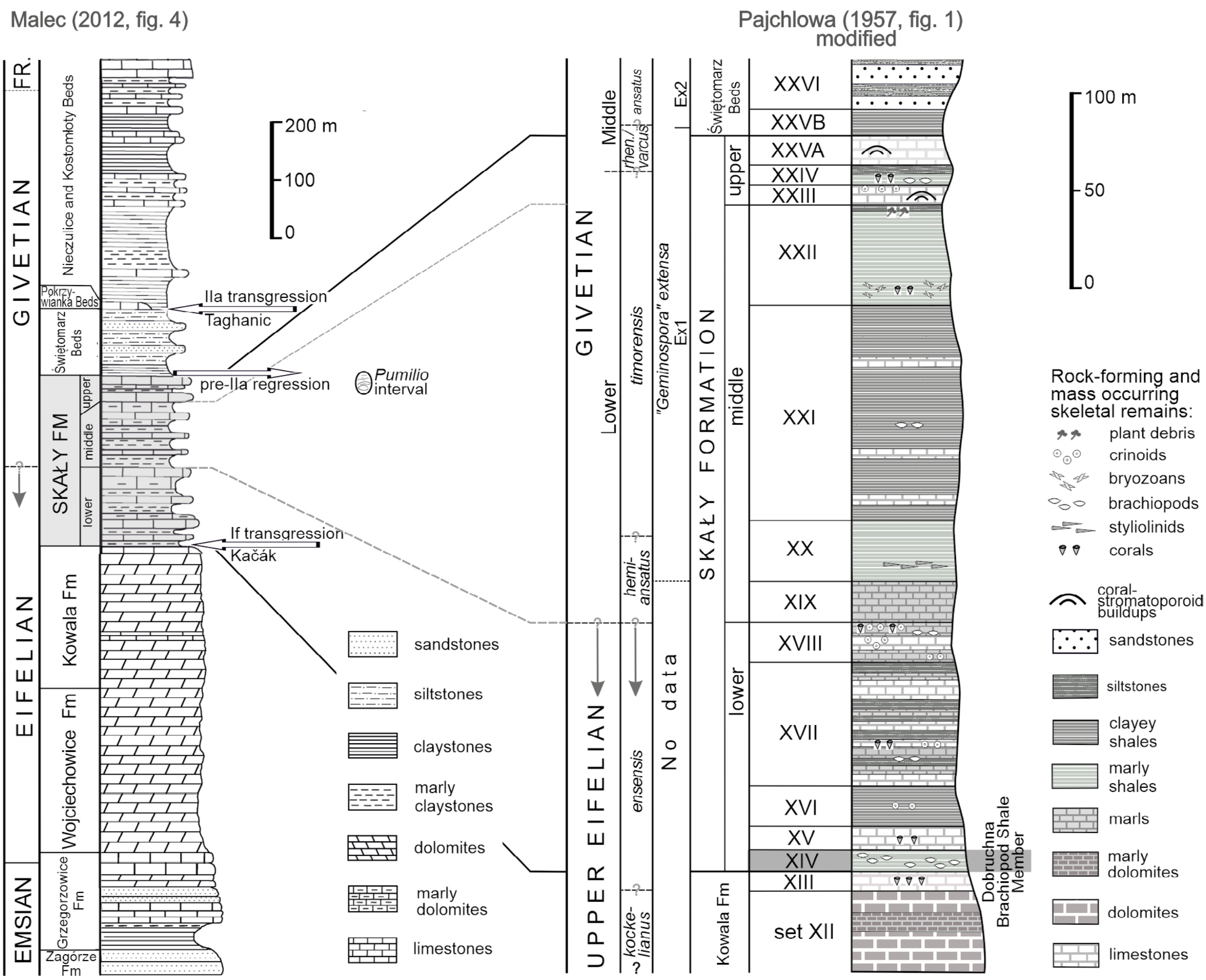

Fig. 5. Emsian to Frasnian lithostratigraphic column of the Grzegorzowice-Skały section (left) after Pajchlowa (1957, fig. 1), updated by Malec (2012, fig. 4), as a reference for the present revised succession of the Skały Fm (right), based on Pajchlowa (1957, fig. 1; data also from Różkowska, 1956; Biernat, 1966; figs 2, 3, Kiepura, 1973, fig. 2; Malec and Turnau, 1997), with modifications explained in the text. Revised biostratigraphy after conodont and miospore data from Halamski *et al.* (2022, fig. 9); the grey arrow marks the possibly lower position of the Eifelian–Givetian boundary. Global events and major sea-level changes (empty arrows and ellipse) after Becker *et al.* (2020, fig. 22.11) and Johnson *et al.* (1985; see updated data in Brett *et al.*, 2011), respectively (compare Fig. 9).

SHALY-CALCAREOUS SKAŁY FORMATION

(In Polish: formacja łupkowo-wapienna ze Skał)

Origin of name: From the village of Skały, located 6 km NE of the town of Nowa Słupia.

Previous nomenclature: The first lithostratigraphic term, used to cover the whole succession underlain by carbonate units (*Amphipora* dolomites and limestones) and overlain by siliciclastic units, was proposed by Czarnocki (1950, pp. 42, 325) as the "Skały Series", and was used only in some later works (e.g., Kielan, 1953; Kotański, 1959; Głuchowski, 1981). However, Czarnocki (1950, pp. 43, 334) also used the terms Skały Beds and Skały Stage (in Polish: piętro skalskie) for the unit within Givetian "shaley facies". The most popular were later "Skały Beds", used firstly only interchangeably with the Skały Series by Pajchlowa (1957, pp. 155–156; see also "Couches de Skaly" in Kielan, 1953, fig. 2; Różkowska, 1956). Such two-term practice was shown in a few palaeontological works (e.g., Stasińska, 1958; Kiepura, 1973). Since Pajchlowa (1959), the capitalized name "Skały Beds" is accepted until now as the most appropriate informal designation (e.g., Filonowicz, 1962, 1963; Biernat, 1964, 1966; Kiepura, 1973; Racki *et al*., 1985; Malec and Turnau, 1997; Malec, 1999, 2012; Turnau and Racki, 1999; Racki and Turnau, 2000; Malinowska, 2003; Halamski, 2005, 2008, 2009; Halamski and Racki, 2005; Halamski and Zapalski, 2006; Narkiewicz *et al*., 2011; Zatoń and Krawczyński, 2011; Zapalski *et al*., 2017; Halamski and Baliński, 2018; Zatoń and Wrzołek, 2020).

This incorrect designation "Skały Formation", indicating a formal definition of the sedimentary suite (as claimed by Dzik, 1981, and Marcinowski, 2004), which, however, was not the case, was first applied by Adamczak (1976, p. 278) in a paper devoted to ostracods (see also "Skały Formation" in Duszyńska, 1953, p. 24). Kłossowski's (1985) and Woroncowa-Marcinowska's (2012) revisions were based on the Świętomarz-Śniadka section. Unfortunately, a detailed description can be found only in the unpublished report of Kłossowski (1981). The undefined term appeared in several publications (Dzik, 1981, 2002; Szulczewski, 1981, 1995; Żbikowska, 1983; Skompski and Szulczewski, 1994; Halamski and Zapalski, 2006; Bełka and Narkiewicz, 2008; Wagner, 2008; Skompski, 2015; Turner and Ginter, 2018; Dec, 2020; Dubicka *et al*., 2021).

Definition: Diagnostic features are the variably predominant marly and clayey shale lithofacies, interbedded many times with different types of limestone (including encrinite and biohermal varieties), and a widely changing contribution of skeletal accumulations. The macrofaunal remains are very abundant, diverse and well-preserved, and in places, their mass occurrences have a rock-forming significance (Fig. 5).

Stratotypes: The type area is the eastern slope of the Dobruchna Stream valley, near the village of Skały (Fig. 2A; see also Halamski, 2022, fig. 1). The Skały Fm occurs under a thin to moderately thick (a few metres) loess cover and it is sparsely cropping out in a chain of small natural exposures, scattered along the slope for a distance of ca. 700 m. This succession was documented by Pajchlowa (1957) on the basis of a series of research trenches, and additional field data were provided by Malec and Turnau (1997). The section on the eastern slope of the Dobruchna Stream is therefore considered – despite some reservations, listed below – as the regional reference section (Fig. 5). Fortunately, the lowermost part of the formation, including its base, is clearly visible at present in the active Skała Quarry (the formal name: the Dolomite Mine "Skała I" of Semav Stones Ltd; Figs 6, 7; for a description of the Kowala Formation cropping out in the quarry see Skompski and Szulczewski, 1994). The unit top (as defined below) was temporarily exposed in trench 4, dug by Jan Malec in the northern part of the Grzegorzowice-Skały section (fig. 6 in Malec and Turnau, 1997; Figs 2A, 8A), as well as in outcrop M0 in Miłoszów Wood (Fig. 8B, C).

Lower boundary: The formation base is placed in the Skała Quarry section (coordinates 50°53′42.1″N; 21°09′37.5″E, Figs 6, 7) at the lower boundary of the first continuous layer of brachiopod marly shales (ca. 25–30 cm thick), marked as the first clearly darker shale interval, ca. 1.6 m above the succession of the *Calceola* Beds (set XIII of Pajchlowa, 1957) in the top of the Kowala Fm. Their uppermost part (ca. 2 m) is composed of reddish dolomicrites and bioclastic dolomites with more or less abundant corals (with *Calceola sandalina* as the most characteristic), crinoids, brachiopods and single stromatoporoids. These strata are less affected by dolomitization than the lower part of the unit: crystalline dolomites are completely absent here.

Therefore, the observations in the quarry wall do not confirm the tectonic contact at the base of Skały Fm, i.e., between sets XIII and XIV, as claimed by Pajchlowa (1957, pp. 21, 237). Conversely, including the transitional beds in the basal part of the Dobruchna Mbr, gradual changes in the succession are recorded perfectly (Figs 6, 7):

- a nodular texture gradually appears at the top of the Kowala Fm section;
- the clay admixture gradually increases from discontinuous red dolomicritic shaly horizons between thicker layers of dolomites, by darker and continuous shaly partings in the transitional interval, and finally to a thick brachiopod shale package;
- the colour of sediments shifts from reddish to grey-red to light grey and dark grey;
- the change in faunal composition is also gradual: from *in situ* mass accumulation of corals and stromatoporoids, succeeded by single corals in a dolomicrite matrix, single corals dispersed in a biomicritic matrix dominated by brachiopods, to a mass brachiopod shelly accumulation.

Upper boundary: The upper boundary of the Skały Fm runs within the transition (stressed particularly by Filonowicz, 1968) from the clayey-calcareous lithology of the Skały Fm to the fine-grained siliciclastic Świętomarz Beds. According to the present concept, the boundary corresponds to the top of the highest thick limestone-dominated set, i.e., set XXV of Pajchlowa (1957), corresponding to subset XXVA of Malec and Turnau (1997). The top of the formation defined in this way was exposed temporarily in trench 4 (Malec and Turnau, 1997, figs 2, 6; Halamski, 2022, fig. 1C; Figs 2A, 8A), dug at the bottom of a steep slope (coordinates 50°53′58.6″N, 21°9′23.5″E).

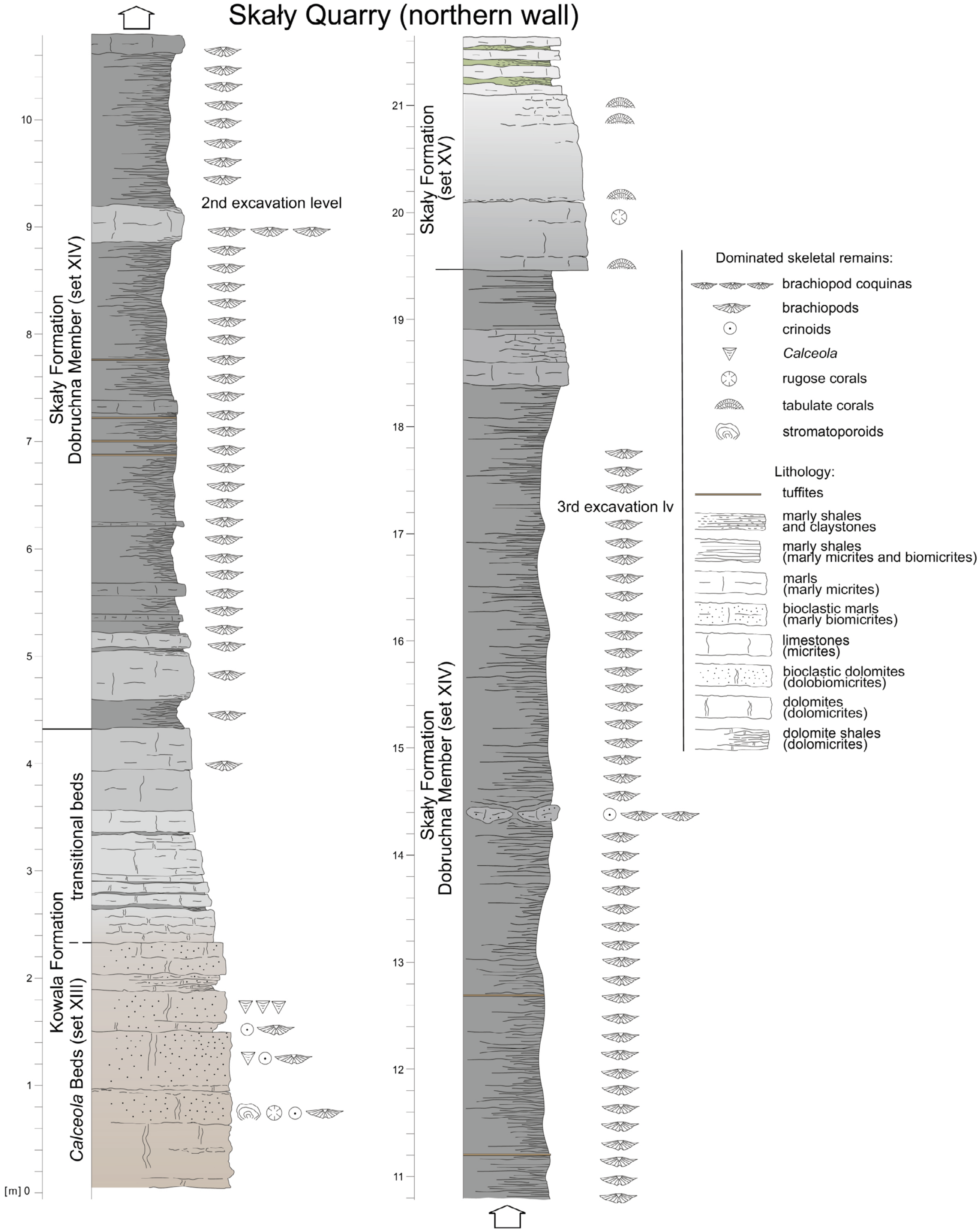

Fig. 6. Stratotype of the lower boundary of the Shaly-Calcareous Skały Formation, and lithological succession (in reference to the primary colouring) of the Brachiopod Shale Member of Dobruchna and surrounding deposits exposed in the northern wall of the Skała Quarry (see Fig. 2A). Sets XIII–XV – after Pajchlowa (1957).

After the reinterpretation of the data of Malec and Turnau (1997), following the original concept of Pajchlowa (1957), the lowest part of the Świętomarz Beds includes now a transitional unit of grey-green and dark grey clayey shales, ca. 15 m thick. In its lower part, there are still single interbeds of micritic limestones that grade upwards into a shaly-sandstone Świętomarz-type suite (Figs 5, 8A). The gradual shift from carbonate- to siliciclastic deposition is clearly recorded in the upper part of the formation (Fig. 5), where a terrigenous admixture and numerous plant remains are reported by Pajchlowa (1957) from set XXII, i.e. 40 m below the formation top.

The hypostratotype, exposing only the basalmost part of the Świętomarz Beds, 1 m thick, is located in the M0 outcrop

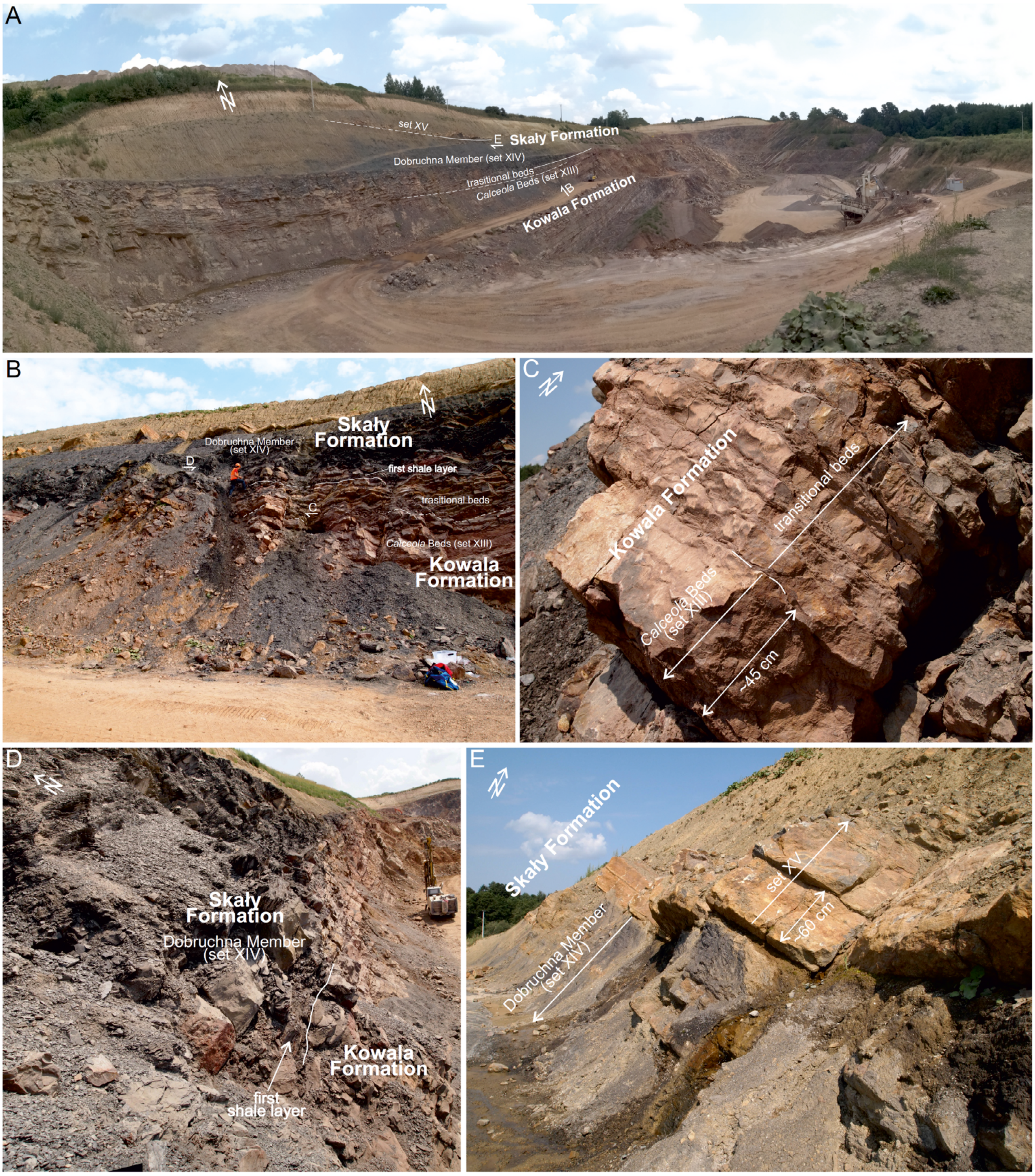

Fig. 7. Stratotype section of the lower boundary of the Shaly-Calcareous Skały Formation (photos taken in July 2021). **A**. Sketch of lithostratigraphic units exposed in the northern wall of the Skała Quarry. **B**. Boundary interval between the Kowala and Skały formations. **C**. Contact between *Calceola* Beds (set XIII of Pajchlowa, 1957) and transitional beds attributed to the uppermost part of the Kowala Formation. **D.** The lowermost part of the Dobruchna Mbr with the first shale layer abundant in brachiopods, indicating the base of the Skały Fm. **E**. The uppermost part of the Dobruchna Mbr and its boundary with the set XV *sensu* Pajchlowa (1957).

at Miłoszów, ca. 6 m thick (see Halamski *et al*., 2022, for coordinates and description; Fig. 8B). The limestone-marly set is sharply overlain by marly to clayey shales (Pisarzowska *et al*., 2022). Because the Devonian bedrock is significantly covered northward under the Quaternary sediments, this exposed interval is assumed to represent merely the lowest part of a much thicker shale package of the lowermost Świętomarz Beds.

Thickness: The Skały Fm is probably between 250 and 280 m thick. According to the most detailed field documentation, summarized in the columnar lithological scheme by Pajchlowa (1957, pp. 155, 157, fig. 1; Fig. 5), it attains

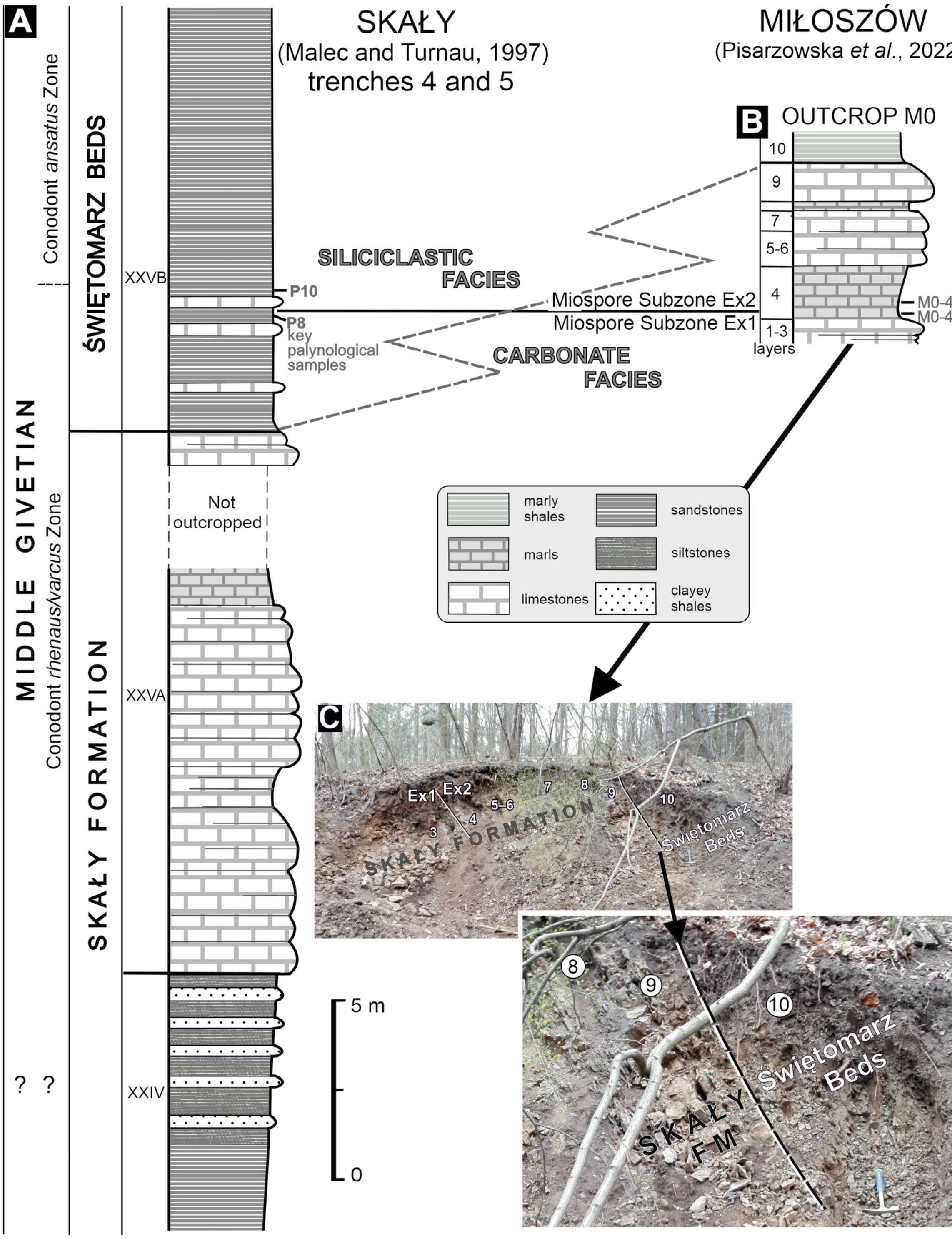

Fig. 8. The upper boundary of the Skały Formation in the Grzegorzowice-Skały stratotype section and the Miłoszów hypostratotype section (see fig. 9 in Halamski *et al*., 2022). **A.** The boundary between the Skały Fm and Świętomarz Beds in trenches 4 and 5 at Skały after Malec and Turnau (1997; figs 2, 6). **B–C.** The boundary interval in the hypostratotype M0 section in Miłoszów (Halamski *et al*., 2022, figs 3B, 4B; Pisarzowska *et al.*, 2022); photo courtesy of A. Pisarzowska. Note the gradual and clearly diachronous transition from carbonate to siliciclastic facies.

367 m (Skały Beds without set XIII; see also Biernat,1966, fig. 2). On the other hand, from data in Malec and Turnau (1997, fig. 3), the thickness of the Skały Fm is only approximately 250–275 m (275–300 m of the Skały Beds, compare with Malec, 1999, 2012), which is more consistent with the cartographic data. The main discrepancy concerns the poorly exposed middle part of the sedimentary suite (see Fig. 5). The width of the formation exposure belt in the Grzegorzowice-Skały-Pokrzywianka area, with dominating dips 35–50º, is between 440 and 500 m, and decreased westward (Czarnocki, 1950; Różkowska, 1956, fig. 1; Pajchlowa, 1957, fig. 5; Filonowicz, 1963). Filonowicz (1963, 1968) calculated the thickness of the Skały Beds as being only 215 m, and a still reduced estimate (170 m) was given by Adamczak (1976), but the latter approximation is biased by a different conception of the unit.

In the Świętomarz-Śniadka section, the formation is graphically represented as being ca. 250 m thick (Czarnocki, 1950, fig. 13; Kłossowski, 1985, fig. 2). Roughly similar estimates were suggested for the incomplete, faulted succession occurring in the boreholes in the Wzdół-Kamieniec area (Osika and Ekiertowa, 1958; Tab. 1), but the thickness increases to more than 350 m in the tectonic re-interpretation of Woroncowa-Marcinowska (2012, fig. 9; SM/Fig. 5B; compare with the structural study of Mizerski, 1981).

Description: The formation is composed of variously alternating packages of grey-olive to black marly and clayey shales, interbedded frequently with mostly dark grey micritic, bioclastic and biogenic limestones (both in rigid tabular/platy and nodular/concretionary layers), with contributions of marls and siltstones. The key diagnostic element is the well-preserved and diverse macrofauna (including brachiopods, corals, crinoids, bryozoans, trilobites, among others), forming variable skeletal accumulations.

This stratigraphic unit is largely erratic in terms of lithofacies, both in vertical and lateral dimensions, and the exact contribution of particular rock types can at present be only roughly assessed. On Czarnocki's (1950) map, this rock suite is marked as "argillaceous shales, nodular and shaly marls with intercalations of limestones". On the basis of compiled thickness data from the Grzegorzowice-Skały section of Pajchlowa (1957, fig. 1; see also Różkowska, 1956, fig. 1; Biernat, 1966, fig. 2; Kiepura, 1973, fig. 2; Fig. 5), the shaly lithofacies is distinctly predominant (ca. 55%),

Table 1

Summary of five areas of outcrops of the Skały Formation (from east to west).

Area	Degree of exposure	Tectonics	Main lithologies	References	Remarks
Grzegorzowice -Skały	Complete succession	Monocline, with minor faults in the northern part	Shales and marls, associated with various limestones; in places crinoid limestones; minor bioherms in the upper part	Pajchlowa (1957); Filonowicz (1968); Malec and Turnau (1997)	Type area of the formation; stratotypes of both boundaries
Cząstków-Miłoszów	?Middle and upper parts	Significantly disturbed by perpendicular faults	Mostly alternating shales and limestones, also crinoid, coral (?biohermal) and brachiopod varieties	Samsonowicz (1934); Halamski *et al.* (2022)	Goniatites in the upper part; hypostratotype of the formation top
Świętomarz-Śniadka-Sitka	Questionably complete succession (uncertain lower part)	Strongly disturbed: overturned folds to the S and numerous longitudinal faults	Shales and limestones (including encrinites); organic buildups absent	Sobolew (1909); Czarnocki (1950); Filonowicz (1968, 1969); Kłossowski (1981, 1985); Woroncowa-Marcinowska (2012)	Goniatite occurrences (Dzik, 2002)
Bodzentyn	Poorly exposed (rubble only)	?	Shales and limestones	Filonowicz (1969)	
Ściegnia (= Wzdół -Kamieniec)	?Middle and upper parts, known solely from drillings (no outcrops)	Faulted and tectonically reduced at least at the base of the shaly series	Light crinoid limestones (30 m), overlain by the most likely thick succession (?above 220 m) dominated by dark shales with marl and limestone interbeds	Osika and Ekiertowa (1958); Filonowicz (1969)	Strongly tectonized succession

with smaller contributions of limestones (above 20%), marls (15%) and siltstones (below 10%). An even stronger dominance of shaly-marly packages over limestones was shown in composite sections of both of the map sheets by Filonowicz (1962, 1963). On the other hand, a higher proportion of calcareous lithofacies emerges from the generalized column in Malec and Turnau (1997, fig. 3) and Malec (2012, fig. 4). Thus, the formation still requires quantitative studies of its petrological/mineralogical and limestone microfacies composition. As demonstrated by the geochemical data from the Miłoszów succession (Pisarzowska *et al.*, 2022), true clayey shales and pure limestones are of minor significance, at least in the upper part of Skały Fm.

The most detailed description is given by Pajchlowa (1957; Fig. 5). Nevertheless, due to the overestimate in thickness of the Skały Fm by this author, paired with some uncertainty in the petrologic data, e.g., an unconfirmed 60 m thick siltstone-rich complex XVII (see also Biernat, 1966), the successional account below is based mostly on the updated survey by Malec and Turnau (1997; see also Malec, 1999), with changes in the basal and topmost parts (i.e. without units XIII and XXVB).

The lower part of the Skały Fm (sets XIV–XVIII), ca. 110 m thick, embraces fossiliferous marls and limestones with marly shales (including encrinites and coquinas, and mesophotic coral "reefs"; see Pajchlowa, 1957; Filonowicz, 1968; Zapalski *et al.*, 2017). A marker layer of coral-crinoidal limestone in the top of set XVIII (see Figs 4, 5), 1.2 m thick, occurs about 100 m above the bottom of the formation. The more argillaceous middle part of the formation, ca. 95 m thick, is tripartite: (1) brownish- and greenish-grey, marly shales with interbeds of bioclastic micrites, overlain by (2) black clayey shales (XXI), and (3) by thick marls, marly shales with limestone and mudstone partings, and few thin sandstone intercalations (XXII). Mass occurrences of pelagic styliolinids are a particularly diagnostic characteristic, paired with the absence of a coral-stromatoporoid fauna.

The upper part of the Skały Fm (sets XXIII–XXVA, ca.} 45 m thick) is again more calcareous. Basal biomicritic lithologies, alternating with marls and marly shales, include a coral-stromatoporoid bioherm, 1.7 m thick. Black and green-grey clayey shales, topped by a 5 m-thick siltstone unit with thin-bedded quartz wackestone intercalations, occurs in the middle part. The uppermost limestone set (XXVA), ca. 15 m thick, is composed of dark-grey biomicritic limestones, succeeded by black bituminous limestones and coral-stromatoporoid biostrome with *Stringocephalus*, and finally topped by marls and micritic limestones (see Fig. 8A).

Geographic range and lateral variation: The Skały Fm can be traced over the entire Łysogóry Region of the HCMts (Bodzentyn Syncline), in the area around the towns of Nowa Słupia and Bodzentyn, from Skały Village in the east to Ściegnia Village in the west (Filonowicz, 1962, 1963, 1968, 1969; Osika and Ekiertowa, 1958; Fig. 1B; Tab. 1).

Small, isolated outcrops of the Skały Fm have been long known (see above) from a few localities west of the Grzegorzowice-Skały section (Fig. 1C), particularly at Cząstków and Miłoszów (Gürich, 1900, pp. 376–377; Siemiradzki, 1903, pp. 121–122, 1909, p. 66, 1922, pp. 142–143; Filonowicz, 1968). Czarnocki (1950) reported several occurrences of the strata in shallow documentation boreholes in this area (e.g., fig. 59; pp. 244–245), but also further NW (Crinoids Beds, p. 195). Samsonowicz (1934) presented more data on lithologically diverse "brachiopod shale" from Miłoszów-Cząstków area, containing *Stringocephalus burtini* and goniatites (e.g., *Maenioceras terebratum*) in the upper part. Only recently, the localities in Miłoszów Wood, 2.5 km to west, could be biostratigraphically correlated with the middle and uppermost part of the Skały Fm (Kondas and Filipiak, 2022; Halamski *et al.*, 2022, fig. 9). It seems that in general, more carbonate facies developed westwards, which is evidenced by the continuous limestone development of the uppermost interval of the Skały Fm (Fig. 8).

According to Kłossowski's (1981, 1985) description, the lower part of the Skały Fm in the Świętomarz-Śniadka section is composed of fossiliferous clay and silty shales, marls and marly limestones. The deposits of the middle part include light grey, medium- and thick-bedded limestones, with rock-forming massive and lamellar stromatoporoids and tabulate corals, and branching rugosans. In the upper fossil-rich unit ("Sierżawy Member") there occur alternating clay and marly shales, marls and marly and grained limestones, up to 30 cm thick (including biointramicrudites). Filonowicz (1968) reported the occurrence of coral limestone bioherms and brachiopods coquinas at Śniadka outcrops. On the other hand, according to Woroncowa-Marcinowska (2012, fig. 4), this unit is dominated by olive-green mica-rich clayey lithologies with a pelagic fauna (tentaculites, ammonoids).

Owing to imprecise time correlation between the Grzegorzowice-Skały and Świętomarz-Śniadka sections (Fig. 4), the lateral facies changes between both these successions are still uncertain:

1. The "crinoid limestone from Sitka" of Kłossowski (1981, 1985) indeed seems to be useful as a local correlative litho-horizon within the Łysogóry Region, as proposed earlier by Sobolew (1909). Similarly, Osika and Ekiertowa (1958) reported 30-m-thick crinoid limestones, directly above the dolomite series, as the basal part of mostly shaly Skały Beds in boreholes west of Bodzentyn (Tab. 1). Czarnocki (1950, p. 43, fig. 13) also considered the Crinoid Beds or Crinoid Level as the basal set of his Skały Series, replaced to the east by shales and brachiopod marls (see below). Therefore, the correlation potential of the crinoid-rich strata needs proper conodont evidence.
2. Woroncowa-Marcinowska (2012), on the basis of the goniatite fauna and the alleged correlation with the Upper *pumilio* Event, assumed that an onset of the sandy clastic facies was as late as the middle part of *ansatus* Zone, i.e., delayed in comparison to the southeastern area. However, this interpretation is not supported by her conodont data.

Remarkably, Filonowicz (1968) suggested a complete wedging out of the deltaic facies of the Świętomarz Beds (Malec, 2012) toward the north (compare Fig. 9), which would imply a direct contact of the described formation with the overlying Nieczulice Beds. This assumption seems generally unsubstantiated, because of the continuation of the unit to the most north-western outcrops in the vicinity of Ściegnia (Filonowicz, 1962, 1969; Woroncowa-Marcinowska, 2005).

Age: Late Eifelian, comprising roughly the conodont *ensensis* Zone (= dacryoconarid lower *otomari* Zone; see below), and reaching the Middle Givetian, at least until the *rhenanus*/*varcus* Zone (Halamski *et al.*, 2022). The previous conodont data indicated that the Eifelian–Givetian boundary "runs within the unit XIX or at its base" (Malec and Turnau, 1997, p. 80), or in the transitional strata of sets XVIII and XIX (Malec, 1999), i.e., in the middle part of the Skały Fm. However, the recent taxonomic revision of the conodont fauna by Katarzyna Narkiewicz (in Halamski *et al.*, 2022) points to a lower position of this boundary (see Fig. 5). The occurrence of the rugosan *Microcyclus* in the shaly set XVI indicates that the Eifelian–Givetian boundary even may be located near this level of the lower Skały Fm. The characteristic button-like genus is reported from the basal Givetian in the Eifel Mountains (Müllert Horizon/Subformation of the Ahbach Fm – Birenheide, 1971; von Nils, 2017; see Brocke *et al.,* 2017, fig. 4) , Morocco (Jakubowicz *et al.*, 2015. tab. 1) and in eastern USA (*Microcyclus* Zone/Bed in the St. Laurent Fm; Brett *et al.*, 2011, p. 34, fig. 9).

The topmost part of the Skały Fm represents the transition interval between the Ex1 and Ex2 miospore subzones (Kondas and Filipiak, 2022; see also Turnau and Racki, 1999). This corresponds to an upper part of the conodont *rhenanus*/*varcus* Zone, although the presence of a lowermost part, the *ansatus* Zone, cannot be excluded (K. Narkiewicz in Halamski *et al.*, 2022). The palynostratigraphic dating reliably indicates the diachronous character of the boundary between the carbonate and clastic facies of the Skały Fm and Świętomarz Beds (Fig. 8). The deposition time of the upper part of the Skały Formation thus corresponds to a time interval immediately preceding the Middle Givetian Taghanic Event and pre-IIa regression (see Figs 5, 9).

Remarks: As highlighted above, the present concept of the Skały Fm differs from that of the Skały Beds (Pajchlowa,1957). The *Calceola*-bearing limestone (set XIII *sensu* Pajchlowa, 1957) is herein included in the Kowala Fm (Figs 6, 7; see also Filonowicz, 1968, p. 27).

In comparison with the Skały Beds in a wider understanding of Malec and Turnau (1997) and Malec (2012), the Skały Fm, as formally defined herein, is additionally modified by transferring the shaly unit XXVB to the Świętomarz Beds (similar to the original definition of the sets XXV–XXVI by Pajchlowa, 1957; in other words, the unit XXVB *sensu* Malec and Turnau, 1997, belongs to set XXVI *sensu* Pajchlowa, 1957; Figs 5, 8A). In fact, the weakest point of the formal unit proposed herein is the recognition of its upper boundary. It may be argued that the formation top could be also placed at the base of the lowest sandstone layer, as postulated by Filonowicz (1968), Malec and Turnau (1997, fig. 3) and Woroncowa-Marcinowska (2012, fig. 4). Such definition is influenced by the appearance of the siltstone-sandstone package(s) well below the top of the limestone-dominated succession (Fig. 5), which limits the accurate recognition of the boundary in fragmentary, lithologically variable and changing over time localities in the faulted successions near Świętomarz and Śniadka (Kłossowski, 1981; Woroncowa-Marcinowska, 2012, fig. 4). Generally, the upper formation boundary is very poorly exposed at present in both the Grzegorzowice-Skały and Świętomarz-Śniadka sections and future work may lead to its reconsideration.

A general NW-ward deepening trend of the Skały strata deposition (see below) seems to be partly evidenced by goniatite and nautiloid occurrences and a non-reefal coral assemblage (small solitary groups) in the Świętomarz-Śniadka section (Sobolew, 1904, 1909; Samsonowicz, 1934; Kłossowski, 1981, 1985; Malec, 1999; Dzik, 2002; Woroncowa-Marcinowska, 2012; but see Czarnocki, 1950, p. 42); also fish and pteraspidomorphid vertebrate remains were reported by Turner and Ginter (2018) and Dec (2020). On the other hand, shallow-water carbonate, partly biogenic deposition and synsedimentary reworking seems to be limited to the northern (Śniadka) area (Filonowicz, 1969; Kłossowski, 1981, 1985). Thus, an overall mosaic facies pattern, controlled by growth of organic buildups in the carbonate ramp setting and/or active synsedimentary tectonics along the major perpendicular Łysogóry Fault (Fig. 1B), is quite probable (Halamski *et al*., 2022).

In the case of small, isolated outcrops, recognition of the Skały Fm may be problematic and the unit can be misidentified as the poorly-known Nieczulice Beds, also displaying variable clayey-calcareous lithologies (cf. the composite section of the Nieczulice Beds by Malec, 2012, fig. 4; Fig. 5; see also Filonowicz 1963, 1968; Kłossowski, 1981, 1985; Malec and Turnau, 1997; Malec, 1999; Turnau and Racki, 1999). This issue is exemplified by the Ściegnia section (formerly Wzdół Plebański), some 8 km west of the town of Bodzentyn. There, the shaly-limestone conodont-dated 8-m-thick strata were considered to be the Lower to Middle Givetian (Lower–Middle *varcus* Zone) by Woroncowa-Marcinowska (2005), thus potentially corresponding to the upper part of the Skały Fm (Malec and Turnau, 1997; Figs 5, 8). Nevertheless, the revised biostratigraphy of the section points to the occurrence of the Middle Givetian *ansatus* Zone (K. Narkiewicz, pers. comm., 2022), which would support assignment of the Ściegnia section to the lower part of the Nieczulice Beds (compare the Lower Frasnian succession at Ściegnia in Dzik, 2002, fig. 4; Jagt-Yazykova *et al*., 2006, fig. 2). Conversely, an isolated outcrop with a rich brachiopod fauna at Błonia Sierżawskie, near Świętomarz, interpreted usually as belonging to the Skały Beds (e.g., Sobolew, 1909; Halamski and Segit, 2006), actually may represent the Nieczulice Beds (unpublished palynostratigraphic data, M. Kondas and P. Filipiak). Overall, however, the Nieczulice Beds, ca. 400 m thick and spanning the Middle Givetian to Lower Frasnian, differ from the Skały Fm in the dominance of shale packages more than 50 m thick (see Filonowicz, 1969 for a non-existent brickyard section in Bodzentyn, fig. 1) and in the scarcity of skeletal accumulations (cf. Czarnocki's shale facies 1950; Pajchlowa 1957). In this context, mass occurrences of the characteristic large-sized rhynchonellid *Phlogoiderhynchus polonicus* in the middle part of the Nieczulice Beds are highlighted by Malec (1999; see also the crinoid-brachiopod strata at the Wł-st site in Turnau and Racki, 1999, fig. 4).

DOBRUCHNA BRACHIOPOD SHALE MEMBER

(In Polish: ogniwo łupka ramienionogowego Dobruchny)

Origin of name: From the Dobruchna Stream, tributary of the Pokrzywianka River, which transects the succession in the W and NW neighbourhood of the Skała Quarry (Figs 1C and 2 A).

Previous nomenclature: Set XIV of Pajchlowa (1957); preceded by broadly understood (see Fig. 4) Brachiopod Marl of Gürich (1896, p. 104) and Sobolew (1904, p. 71), *Calceola* shale or marly shale of Sobolew (1903–1904, pp. 8 and 19; Fig. 3G), brachiopod shale of Sobolew (1909, p. 276) and lower shaly beds (Siemiradzki, 1922, p. 145). Popularized in the literature as "brachiopod shales" (e.g., Duszyńska, 1953; Kotański, 1959; Biernat, 1964, 1966; Adamczak, 1976; Piotrowski, 1977; Dzik, 1981; Halamski, 2009; Dubicka *et al*., 2021).

The term Brachiopod Shale Member from Dobruchna (in Polish: "ogniwo łupka brachiopodowego z Dobruchny") was introduced by Kłossowski (1981, 1985) after studying the Świętomarz-Śniadka section, but it referred – after Sobolew (1909) – to a broad association of lithologies, as an equivalent of a lowermost Skały Fm (see also Woroncowa-Marcinowska, 2012; Fig. 4). In spite of the lack of a complete, well-documented description, the "member" is referred to as the formal lithostratigraphic unit, briefly described by Marcinowski (2004) in his inventory of the Polish lithostratigraphic units.

Definition: A set of dark grey marly shales with abundant and well-preserved brachiopod shells (partly forming coquinas), interbedded with mostly grey marls, with subordinate intercalations of thin layers of variegated tuffites (Figs 6, 7).

Stratotype: Northern wall of the Skała Quarry (see Skompski, 2015; Figs 2A, 7) on the 2nd and 3rd excavation levels.

Boundaries: The lower boundary of the Dobruchna Mbr runs at the base of the first continuous shale layer (ca. 25–30 cm thick). This layer is the clearly darker shale interval, lying above the succession of thin-layered grey marls, ca. 1.6 m in thickness (transitional beds; Fig. 7). Below, lighter, brown-weathered dolomites with *Calceola* assemblage (*Calceola* Beds, set XIII of Pajchlowa, 1957) occur (Fig. 6).

The upper boundary is situated at the base of the first massive limestone layer. Two thick-bedded, brown-weathered limestone layers, with an assemblage of tabulate and rugose corals, protruding at the 3rd excavation level in the northern wall of the Skała Quarry (set XV of Pajchlowa, 1957; Fig. 7), contrast with the clearly darker interval of the underlying brachiopod shales (see also the trench A section in Woźniak *et al.*, 2022). Above, the thick succession of greenish marly shales and claystones, interbedded with thin layers of marls and marly limestones, occur.

Thickness: 15.1 m in the succession exposed in the E-part of the Skała Quarry northern wall; probably increasing to ca. 20 m in the western part of the wall (Fig. 7). In the Pajchlowa excavations, located ca. 200 north-west of the stratotype section (Fig. 2A), this thickness was assessed as 12 m (Pajchlowa, 1957; Adamczak, 1976) or only 8 m (Halamski and Zapalski, 2006).

Description: The Dobruchna Mbr consists mostly of dark grey marly shales, with an abundant and varied assemblage of brachiopods, whose presence is a characteristic macroscopic feature of the unit. Shale lamination is manifested as alternating discontinuous laminae of marl (in places grained marl/grainstone) and clay, interrupted by skeletal material – mostly brachiopod shells. Brachiopods occur as single specimens, dispersed in a marly/clayey matrix or form up to 30-cm-thick coquinas (in places with important admixtures of crinoid detritus). Subordinately, thin to medium layers of grey marls occur in the lower and upper part of the unit (Fig. 6), with less abundant, dispersed brachiopods and lacking apparent lamination. The fossiliferous strata are largely grey-olive to grey-greenish in weathered rocks. In petrological terms, brachiopod shales of the upper Dobruchna Mbr, studied by Woźniak *et al.* (2022) in the trench A section, can be classified as marly claystones and clayey marls ($CaCO_3$ content between 6.7 and 42.3%). In addition, at least six few-centimetres-thick layers of brownish tuffites occur in the middle part.

Among the macrofossils (see the list in Halamski and Zapalski, 2006), the most characteristic assemblage of brachiopods is represented by at least forty species (44 given by Halamski and Zapalski, 2006, but at least one should be removed, see Halamski and Baliński, 2019, p. 404). Less common are rugose and tabulate corals (20 and 10 species, respectively), bryozoans (at least 10 species, including hederellids and ascodictyids), trilobites (5 species), tentaculites (2 species), crinoids (2 species, possibly an under-estimation), as well as a single gastropod species.

Geographic range: The only other site is given by Czarnocki (1950, p. 43) from a well at Kolonia Włochy, 1 km to the west of the stratotype section.

Only the Grzegorzowice-Skały section may include a completely developed Skały Fm with Dobruchna Mbr in the base (Tab. 1; Fig. 4). The occurrence of the member (or its lateral equivalents) in the Świętomarz-Śniadka section raises some doubts concerning both the lateral facies change (see above) and/or possible tectonic reduction (see the different views in Sobolew, 1909; Czarnocki 1950; Filonowicz 1968; Adamczak, 1976, p. 292; Kłossowski 1981, 1985; Malec, 1999; Woroncowa-Marcinowska, 2012).

Age: Late Eifelian (probably the conodont *ensensis* Zone; dacryoconarid lower *otomari* Zone; see also Dzik, 1981, 2002; K. Narkiewicz, in Halamski *et al*., 2022). The brachiopod fauna of the Dobruchna Mbr, especially *Primipilaria primipilaris* and *Isospinatrypa aspera aspera*, is most likely coeval to that of the Upper Eifelian Freilingen Formation of the Eifel (Halamski, 2005).

Remarks: The highly fossiliferous package was proposed as an Upper Eifelian Konzentrat-Lagerstätte by Halamski and Zapalski (2006; see also Halamski, 2002), who listed over 130 taxa from 14 fossil animals and two microfaunal groups, reported from the Dobruchna Mbr.

Characteristic and/or particularly abundant brachiopod species, in places of rock-formation in the coquinoid knobs, include the productide *Poloniproductus varians*, the orthide *Aulacella prisca* (= *A. eifliensis* auct.), the atrypide *Atrypa*

(*Planatrypa*) *depressa*, and the spiriferide *Eleutherokomma diluvianoides* (see Biernat, 1966; Halamski, 2004, 2009; Woźniak *et al.*, 2022).

It is worth noting that the Dobruchna Mbr used to crop out in a locality, known informally as "the fundamental pit" (in Polish: dziura podstawowa) or "the brachiopod pit" (see also Musialik, 2020). This is outcrop SK-3 *sensu* Halamski (2009), visited by generations of professional palaeontologists, geology students, and amateur fossil collectors. This site was covered by rubble during the extension of the Skała Quarry in the late 2010s and is not accessible at present. Near this pit, a 5.6-m-thick succession of the upper part of the Dobruchna Mbr and set XV of the Skały Fm was exposed in the temporary (1989) trench A (Woźniak *et al.*, 2022). The northern wall of the Skała Quarry (as of 2022) is situated less than 100 m from the former outcrop SK-3. Alternating shales and limestones, temporarily cropping out in a road escarpment eastwards from the Skała Quarry, sampled in about 2019 and reported as the brachiopod shales (Dubicka *et al.*, 2021; compare Gajewska, 2022, fig. 1 for a revised interpretation), do not fall within the definition of the Dobruchna Mbr, understood here as argillaceous succession without any limestone intercalations.

REGIONAL COMPARISONS

The Skały Fm, as defined in the present paper, is confined to the Łysogóry (Northern) Region of the Palaeozoic core of the HCMts. Nevertheless, its lateral counterparts can be traced in neighbouring regions within the wider pattern of the Devonian basins of the Variscan foreland in Poland (Narkiewicz, 2020).

The Łysogóry Region corresponds to the southern margin of the Łysogóry Basin, extending further to NE under a Permian–Mesozoic cover up to the edge of the East European Craton (Teisseyre-Tornquist Zone). The Middle Devonian strata, studied in a few deep borehole sections, located in this area (Narkiewicz, 2011), can be compared with the exposures of the northern HCMts. The combined litho-biostratigraphic correlation indicates that the Skały Fm is a temporal and facies equivalent of the Marls and Calcareous Shales Unit (ca. 250 m thick) in the Szwejki IG 1 section, near the NE margin of the Łysogóry Basin, and the Upper Dolomitic Shales Unit (ca. 70 m thick) defined in the Ostałów 1 section as being representative of the axial part of the basin (Narkiewicz *et al.*, 2011).

Both units are characterized by a carbonate-shaly lithofacies with a variable proportion of skeletal accumulations, including brachiopods, crinoids, corals and less common stromatoporoids. The depositional system is interpreted as an open-marine shaly-carbonate shelf with a shallowing trend, eventually passing upwards into shallow-marine clastics. The latter, defined as the Ostałów Fm, are believed to correspond to the Świętomarz Beds of the Łysogóry Region (Narkiewicz *et al*., 2011). The NE basin margin in its SE segment is characterized by a development of a carbonate-terrigenous platform, defined as the Dolomites with Stromatoporoids and Corals Unit, which is more than 80 m thick (Narkiewicz, 2011). These deposits are succeeded by marine sandstones of the 10-m-thick Ostałów Fm.

The Łysogóry Basin/Region is limited from the south by the Holy Cross Dislocation (Fig. 1B), a deep-rooted crustal discontinuity, which acted as a synsedimentary fault zone during the Devonian. It separated the Łysogóry

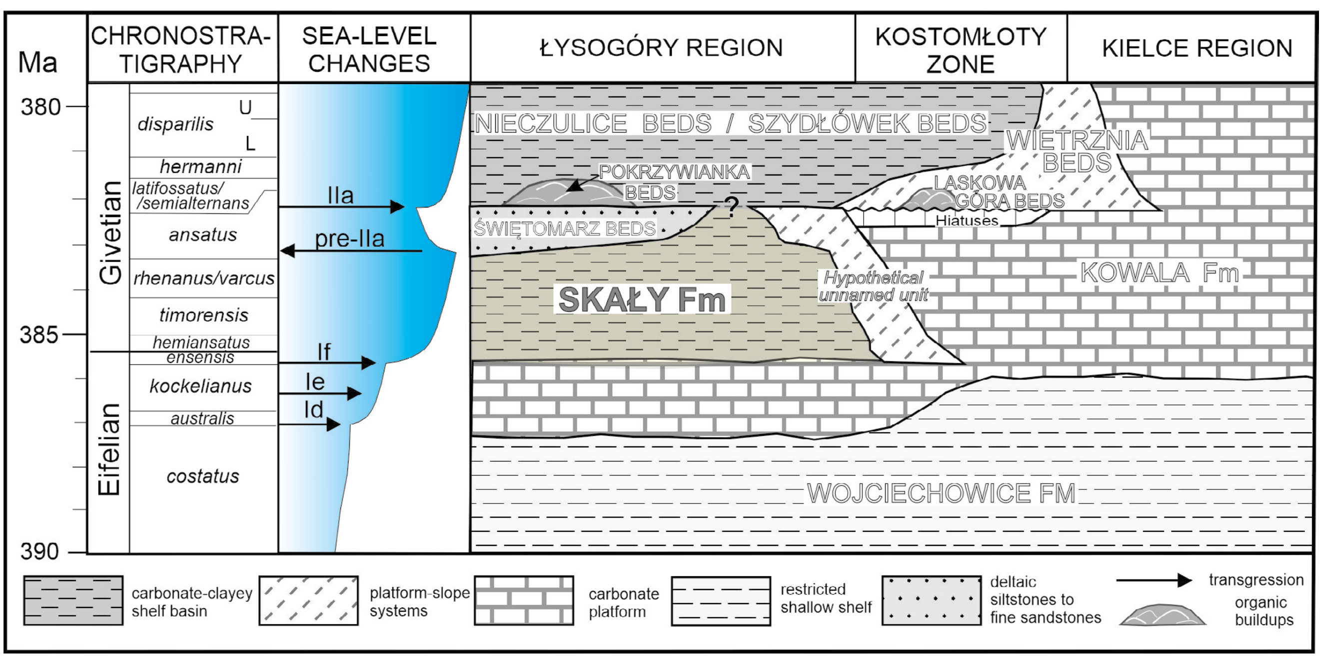

Fig. 9. Position of the Skały Formation in the chronostratigraphic cross-section, showing interpreted depositional architecture of the Middle Devonian in the western part of the Holy Cross Mts (according to Narkiewicz and Narkiewicz, 2010, fig. 6; chronostratigraphy corrected after GTS 2020, Becker *et al.*, 2020). The regional relative sea-level curve is shown against the eustatic cycles of Johnson *et al.* (1985); their boundaries being adjusted to the current chronostratigraphy (see also the revised concept in Brett *et al.*, 2011, and Becker *et al.*, 2020; fig. 7D in Halamski *et al.*, 2022).

Basin, displaying relatively deeper-marine facies and increased subsidence, from the more stable and shallower-water Małopolska Basin. The Middle Devonian sediments of the northern part of the latter basin are exposed in the Kielce (southern) Region of the HCMts, with a transitional Kostomłoty Zone adjoining the Holy Cross Fault (Racki, 1993; Szulczewski, 1995).

Stratigraphic correlation across the Holy Cross Fault zone (Narkiewicz and Narkiewicz, 2010; Fig. 9) clearly demonstrates diachronous and stepwise southwards encroachment of a carbonate-clayey shelf-basinal facies, typified by the Skały Fm and Nieczulice/Szydłówek Beds (e.g., Malec, 1999). The deposition of the Skały Fm is linked to a gently sloping, muddy deep-ramp system, developing during the Middle Devonian cooling interval (Halamski *et al.*, 2022; Pisarzowska *et al.*, 2022). The drowning events and the resulting crises of the carbonate factory closely correspond to the eustatic sea-level cyclicity (Fig. 9). Also, the diachronous onlap of the Middle Givetian deltaic system in the Łysogóry domain (Malec, 2012) took place during the fluctuating pre-IIa sea-level fall (Figs 8, 9; see also Malec, 1999 and Turnau and Racki, 1999, fig. 8). but this facies shift was likely triggered mainly by tectonic activation in western Volhynia (Ukraine); Kuleta and Malec, 2015).

Drowning of the carbonate platform and the onlap of shelf-basinal strata occurred already in the Late Eifelian in the Łysogóry Region, whereas the platform existed up to the mid-Givetian in the Kostomłoty Zone (Racki *et al.*, 1985) and up to the Middle Frasnian in the Kielce Region to the south (Racki, 1993; Narkiewicz *et al.*, 2006). As a consequence of this facies diachroneity, the age equivalent of the Skały Fm in the latter region is the coral-stromatoporoid platform of the Kowala Fm. The regressive development near the top of the Skały Fm and its passage into the clastic Świętomarz Beds correspond to short-term erosion predating the development of the Laskowa and Szydłówek Beds (Racki *et al.*, 1985) and related backstepping of the Kowala platform (Fig. 9). This episode is less clear in the platform interior in the central parts of the Kielce Region, where time-equivalents of the Skały Fm are represented by the thick biostromal-lagoonal series of the *Stringocephalus* Beds, without any distinct stratigraphic trend in facies evolution (Racki, 1993).

FINAL REMARKS

"A small, narrow valley, full of picturesque views, stretching between Grzegorzewice and the villages of Skały and Zagaje" (Zejszner, 1870, p. 24) was regarded as one of the most significant continuous Devonian geological sections in the HCMts region already by Zeuschner (1869, p. 263) and Sobolew (1909, p. 79). The prophecy materialized in the second half of the twentieth century in a series of monographs on different groups of fossils, and finally led to the proposal of the Late Eifelian Konzentrat-Lagerstätte at Skały by Halamski and Zapalski (2006).

However, this advancement is in fact limited to the comprehensively understood palaeozoological aspects of highly fossiliferous units, whereas – as highlighted above – even the thickness and lithological features of the entire formation are unclear. Therefore, with the revival of research in the last decade, more multidisciplinary, especially sedimentological, geochemical and palaeoecological projects are to be expected. This was partially achieved in the case of the Miłoszów section (Halamski *et al.*, 2022; Pisarzowska *et al.*, 2022), and in the current coral and foraminifera works (Jakubowicz *et al.*, 2015; Dubicka *et al.*, 2021).

On the basis of a brief communication by Dzik (1981, 2002), reporting the pelagic dacryoconarid *Nowakia otomari* from set XIV (Dobruchna Mbr), it may be expected that the base of the Skały Fm corresponds not only to the global carbonate crisis, driven by the If transgression (Fig. 9), but also to the Kačák Event and thus to the onset of the Kačák Episode (House, 1996; Walliser, 1996; Narkiewicz *et al.*, 2021). The latter appears as an important turning point in the development of Devonian terrestrial and marine ecosystems, and thus a current study of the global event in the Skały succession may be particularly informative in that respect. Paradoxically, the crisis time is distinguished in the Łysogóry Region by biodiversification maxima of many benthic groups. On the other hand, the upper slice of the described formation is important in assessing biotic effects during the more drastic Middle Givetian Taghanic Crisis (Halamski *et al.*, 2022; see Fig. 5), whilst the regional record of mysterious *pumilio* episodes (i.e., brachiopod-styliolinid accumulations; Becker *et al.*, 2020) remains speculative (see Woroncowa-Marcinowska, 2012, p. 359; Pisarzowska *et al.*, 2022).

To advance high-resolution studies of the Middle Devonian succession in the Łysogóry Region, including very poorly known Upper Devonian strata, a moderately deep borehole would be very helpful. It should be located in a carefully selected area, that is, after a geophysical survey, limiting potential tectonic obstacles. The optimum location is in the axial zone of the Bodzentyn Syncline, near the village of Nieczulice, where the well could penetrate, above the Middle Devonian also the Frasnian and at least the lower part of Famennian (*crepida* Zone – Krul, 1995). Similar work in the areas located westward are confined by the far more intensive tectonic disturbances of the coeval Devonian strata (Czarnocki, 1950; Osika and Ekierowa, 1958; Filonowicz, 1962, 1969; Mizerski, 1981; SM).

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SUPPLEMENTARY MATERIAL TO:

Racki, G., Wójcik, K., Halamski, A. T. & Narkiewicz, M., 2022. Middle Devonian Skały Formation in the Holy Cross Mountains (Poland) – formal description and subdivision based on new field data. *Annales Societatis Geologorum Poloniae*, 92: 425–444. https://doi.org/10.14241/asgp.2022.18

EVOLVING TECTONIC CONCEPTS OF THE CENTRAL PART OF BODZENTYN SYNCLINE BETWEEN ŚWIĘTOMARZ AND ŚNIADKA, AS EXPOSED ALONG PSARKA RIVER (SEE FIG. 2B)

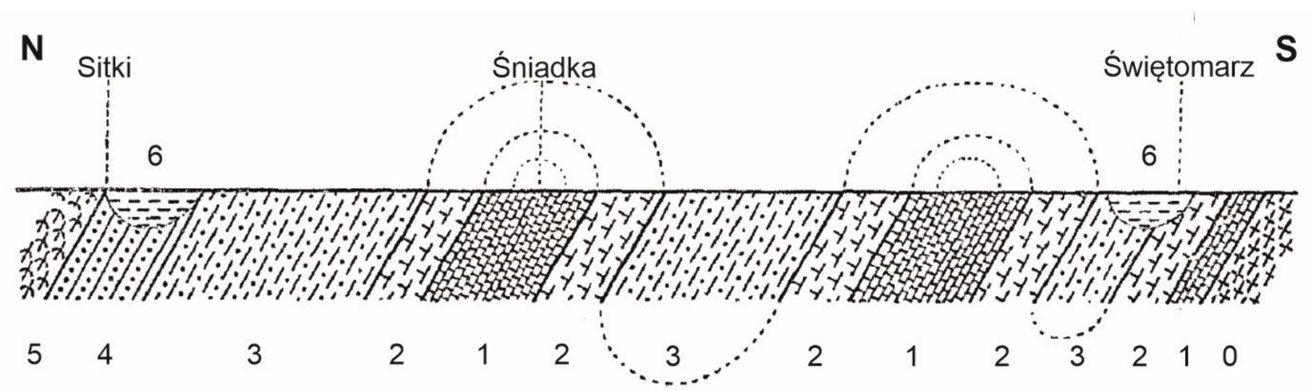

Fig. 1. Świętomarz-Śniadka section after Siemiradzki (1903, fig. 1 , p. 118), based on Gürich (1896, map in p. 57).
0 – Lower Devonian quarzites, 1 – greywacke shales without fossils, 2 – Middle Devonian shales with *Reticularia*, 3 – Middle Devonian beds with *Bifida*, 4 – Crinoid beds, 5 – Coral dolomites, 6 – Upper Devonian shales with *Buchiola retrostriata*.

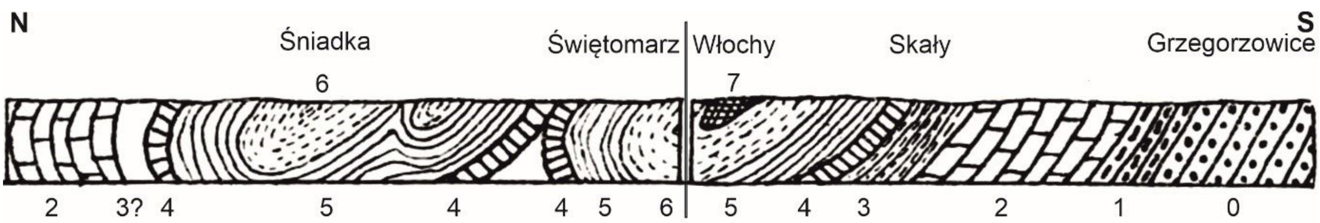

Fig. 2. Combined section through the Northern (= Bodzentyn) Syncline after Sobolew (1909, fig. 2 , p. 155).
0 – Klonów Sandstone, 1 – Grzegorzowice Beds, 2 – dolomite, 3 – Brachiopod Shale, 4 – Crinoid Limestone, 5 – Sierzawy Beds, 6 – Świętomarz Beds, 7 – Kadzielnia Limestone.

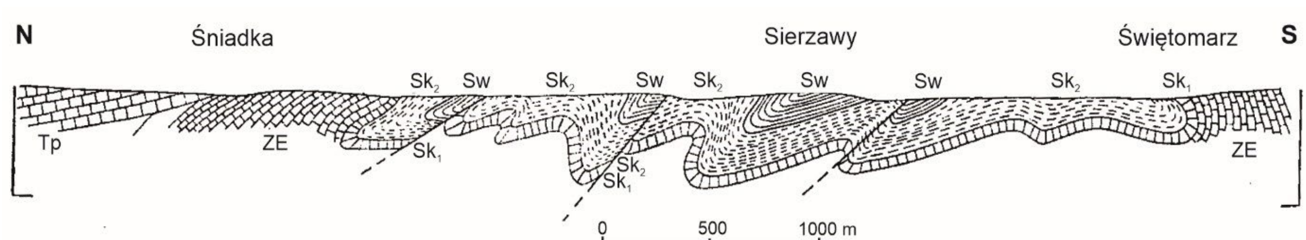

Fig. 3. Świętomarz-Śniadka section after Czarnocki (1950, fig. 13B).
ZE – Givetian and Eifelian dolomites, Sk_1 – crinoid beds (basis of the Skały series), Sk_2 – Skały series, Sw – Świętomarz series, Tp – Bunter Sandstone.

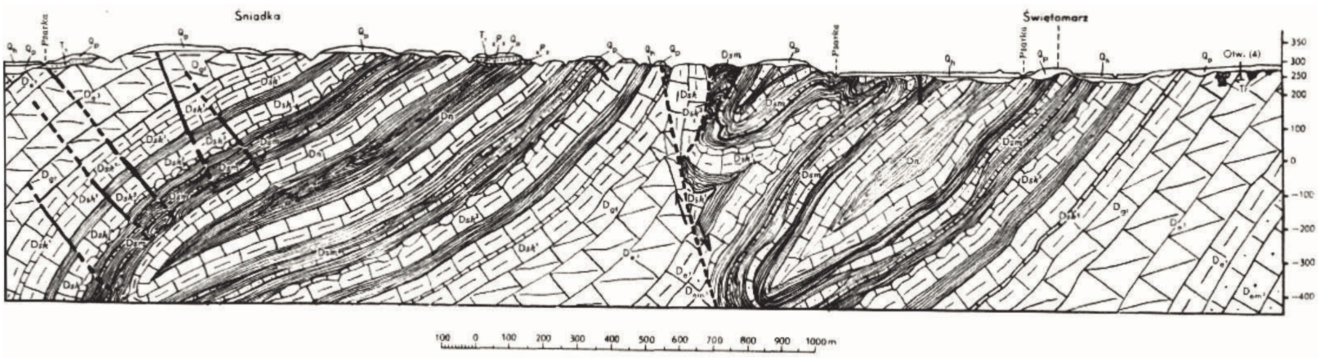

Fig. 4. Świętomarz-Śniadka section after Filonowicz (1968, plate 7).
Devonian: D_{em1} – sandstones and shales (Emsian), D_e^1 – marls and limestones (Eifelian), D_e^2 – dolomites and marls (Eifelian), D_{gt} – dolomites (Givetian), D_{sk}^1 – lower Skały beds (marls with intercalations of shales and limestones; Givetian); D_{sk}^3 – upper Skały beds (shales and marls with intercalations of nodular limestones; Givetian); D_{sm} – Świętomarz beds (shales and sandstones; Givetian), D_n – Nieczulice beds (shales, marls and limestones). Explanations for rocks other than Devonian omitted.

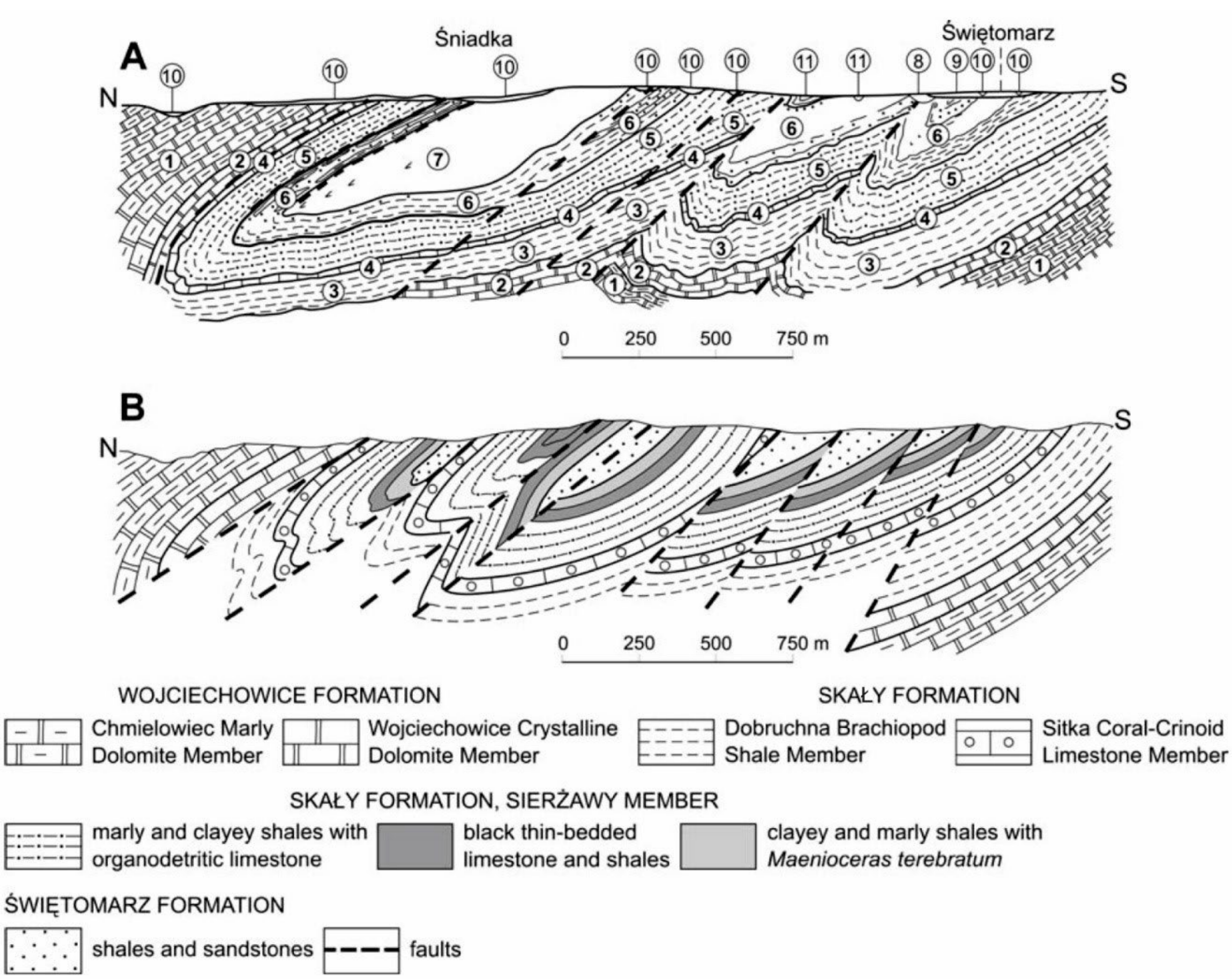

Fig. 5. Świętomarz-Śniadka section after Kłossowski (1985, fig. 2; **A**) and Woroncowa-Marcinowska (2012, fig. 9B; **B**), shown jointly for comparison in figure 9 by Woroncowa-Marcinowska (2012).
Explanations refer to numbers in circles (**A**): 1 – Wojciechowice Formation, Chmielowiec Marly Dolomite Member; 2 – Wojciechowice Crystalline Dolomite Member; 3 – Skały Formation, Dobruchna Brachiopod Shale Member; 4 – Sitka Coral-Crinoid Limestone Member; 5 – Sierżawy Member; 6 – Świętomarz Formation; 7 – Śniadka Formation; 8 – Zechstein conglomerates; 9 – Buntsandstein; 10 – loess; 11 – deluvia.